

APPENDIX D

Example of Pond Detention Storage Computations

POND DETENTION STORAGE COMPUTATIONS

Introduction

Computations for detention storage are done in two main steps:

- (1) Computing Inflow Flood Hydrographs for the 2-year and 10-year recurrence interval 24-hour rainfall events, using the Soil Conservation Service's TR-55 Tabular Hydrograph Unit Discharges procedure. These will be done for both the pre-project and post-project conditions.
- (2) Routing the Inflow Flood Hydrographs through the pond using a simplified spreadsheet-based computation procedure known as "Chain Saw Routing" (developed by Dr. H. R. Malcom of the North Carolina State University). In the routing computation procedure, the pond's spillway control design features (such as weir crest length or riser size) will be adjusted (through trials) to result in the outflow hydrograph peak to be no larger than the corresponding value for the pre-project condition.

The detailed steps in the computation procedures are described below.

Inflow Flood Hydrograph

Perform the following steps for the **pre-project and post-project conditions** for both the **2-year and 10-year rainfall events**.

- (1) Compute the composite (weighted) Curve Number (CN) for the site area draining to the pond.
- (2) Determine the Time of Concentration (T_c) for the site using any generally accepted methods.
- (3) Using Figure 1, read the Direct Runoff (Q) in inches for the respective value of CN.
- (4) Using Table 1, read the value of I_a (Initial Abstraction) for the respective value of CN.
- (5) Using Table 2, for the known T_c and I_a/P values, read the values of Time (in hours) and Tabular Hydrograph ordinates (csm/in) and enter them in columns A and B of the "Chain Saw" Flood Routing spreadsheet described in the following section "Flood Routing." For Greensboro, P (the 24-hour rainfall) is 5.1 and 3.5 inches during 10-year and 2-year rain events respectively. To select the appropriate values of hydrograph unit discharges in Table 2, either round off the calculated value of I_a/P to the nearest value (0.1, 0.3, or 0.5) given in Table 2 or interpolate the values of the hydrograph unit discharges to correspond to the calculated value of I_a/P .

Inflow flood hydrograph ordinates for various times are given by the following equation.

$$q = A_m \cdot Q \cdot q_t = (A/640) \cdot Q \cdot q_t$$

where, q = Inflow hydrograph ordinate value (in cfs),

A_m = Drainage area (including pond) in square miles,
 A = Drainage area (including pond) in acres,
 Q = Runoff in inches (from step 3),
 q = Tabular hydrograph ordinate value

Inflow hydrograph ordinate values need not be computed in this step, since they will be computed as a part of the flood routing spreadsheet discussed in the following section.

Flood Routing

Perform the flood routing in the pond using the "Chain Saw" method that facilitates the computations using any commercial spreadsheet software (such as Excel or Lotus 123).

The basic continuity equation applicable to the flood routing process is

$$\Delta S = (I - O) \cdot \Delta T$$

where, ΔS = Change in storage during a time interval,
 ΔT = Time interval,
 I = **Average** inflow during the time interval,
 O = **Average** outflow during the time interval

To enable computations using a spreadsheet, the Inflow and Outflow values at the **beginning** of a time interval, **instead of the average** values for the time interval, are used in the procedure for computing incremental storage. The governing equation thus becomes:

$$\Delta S_{ij} = (I_i - O_i) \cdot \Delta T_{ij}$$

This equation is used in the spreadsheet to compute incremental storage during various time intervals and the cumulative storage at the corresponding times.

Table 3 illustrates a typical spreadsheet used for storage routing computations for a 20 acre site, with pre-project CN=70 and post-project CN=90. The pond is assumed to be 160 ft. X 80 ft. (0.3 acre) in size, with side slopes of 3H:1V. The principal spillway is assumed to be a weir with crest at the normal pool level and $C = 3.3$. A 3-inch diameter drain, located 1 foot below the principal spillway crest level is assumed to function as an orifice with a discharge coefficient of 0.6. The spreadsheet shows the computations for the 10-year recurrence rain. Figure 2 shows the graph of the inflow and outflow hydrographs. The length of the weir required was found (as discussed in step 10 below) to be 0.9 ft. to match the post-project flood peak with the pre-project value of 42 cfs. The storage required, as may be seen in Table 3 (cell D20), is 94,942 cubic feet (2.18 acre-feet). The corresponding maximum stage (depth) is seen (in cell G20) as 5.8 feet.

Following are the steps in using the spreadsheet.

- (1) Initialize the first row in the computations, say row # 10 (assuming rows 1 through 9 are used for title, descriptive text, and column headings), by entering 0 (zero) in all the cells. In the first cell for time (A10), you may alternatively enter the time

corresponding to one time interval before the start of the inflow (say, 10.5 hours if inflow values in Table 2 start at 11.0 hours).

- (2) Enter the data for time and the corresponding inflow hydrograph unit discharges read from Table 2 in columns A and B respectively, starting with the second row (row # 11; cells A11 and B11).
- (3) In the second row of computations, enter 0 or a small (nominal) value in the cell for outflow (G11), since outflow at the start is unknown.
- (4) In cell C11, enter the formula for the Inflow (q) as given in step 5 under "Inflow Flood Hydrograph" above: $=(\text{value of A.Q}/640)*(B11)$. Copy the formula from cell C11 and paste into all the cells below that in column C.
- (5) In cell D11, enter: $=(D10+(A11-A10)*3600*(C10-G10))$. Copy the formula from cell D11 and paste into all the cells below that in column D.
- (6) In cell E11, enter: $=(D11-D10)$. Copy the formula from cell E11 and paste into all the cells below that in column E.
- (7) In cell F11, enter the formula for the stage in terms of storage. For convenience, consider the zero value for stage as the crest elevation of the principal spillway, which in most cases would be the normal pool elevation in a pond. Develop data for the area (a) of the pond at the principal spillway (normal pool: zero stage) elevation and various stages (h) above the principal spillway elevation from the contour map or proposed grading plan. Calculate the storage volumes (V) for different stages (h) using prismoidal formula: $V = (d/3) * ((a_1 + (a_1 * a_2)^{0.5} + a_2))$, where a_1 and a_2 are the areas of the pond at two stages and d is the vertical distance between the two stages.

The storage volume (V) versus stage (h) relationship for the pond above the normal pool (principal spillway crest elevation) can generally be approximated by an equation of the form:

$$V = k h^n$$

$\log V = \log k + n \log h$; For $h = h_1 = 1$, $\log h_1 = 0$; hence $k = V_1$, where V_1 = volume of storage at $h = 1.0$ ft. stage. Hence, $V = V_1 \cdot h^n$. Determine the values of n from the known pairs of values of V and h. Use the average of the values of n for computations. Alternatively, determine the value of n by plotting the V versus h pairs of values on a log-log paper. With the values of $k = V_1$ and n determined as above, the formula for the stage (h) can be written in terms of storage volume (V) as:

$$h = (V/V_1)^{1/n}$$

Enter the above formula for the stage in cell F11 of the spreadsheet: $=(D11/\text{value of } V_1)^{(\text{value of } 1/n)}$. Copy the formula from cell F11 and paste into all the cells below that in column F.

- (8) In cell G12, enter the formula for the total outflow as equivalent to the sum of the outflows through the various outflow facilities: $=(H12+I12+J12)$. Copy the formula

from cell G12 and paste into all the cells below that in column G. Note that either 0 or a small value was entered in cell G11 in step 3 above.

- (9) In cell H12, enter the formula for orifice discharge: $=4.8 * (\text{value of orifice area}) * (f12 + \text{value of the depth of center of orifice below the zero of stage})^{0.5}$. Copy the formula from cell H12 and paste into all the cells below that in column H.
- (10) In cell I12, enter the formula for the principal spillway discharge: $(\text{value of } C) * (\text{length of spillway}) * (F12 - \text{stage of spillway crest})^{1.5}$. In most cases, the stage of the spillway crest would be zero. Copy the formula from cell I12 and paste into all the cells below that in column I. Since the spillway length required is unknown, a few trial values for the spillway length may have to be entered, each resulting in a unique flood routing and peak outflow value (in column G). The final value to be accepted should be the one that results in the peak outflow value that closely matches or is less than the target value (such as the pre-project runoff peak discharge).
- (11) In cell J11, enter 0. Copy the 0 from cell J11 and paste into all the cells below that in column J. Revise the values in column J only for routing floods larger than a 10-year flood, as given in the following steps.
- (12) After performing the routing computations for detention storage required for the 10-year recurrence rain (no emergency spillway flows up to 10-year flood), the 10-year flood pool elevation would be known. Then, establish the crest elevation of the emergency spillway at or above the 10-year flood pool elevation.
- (13) Revise the values in columns C and J to perform flood routing computations for the 100-year inflow flood, which would provide design information regarding the 100-year flood pool elevation and the discharges through the different outflow facilities. In column C, revise the formula in cell C11 and the ones below that to reflect the revised value of runoff (Q) for the 100-year rainfall. If the emergency spillway crest is set at the elevation of the maximum pool (highest stage) in a 10-year flood event, enter the formula for the emergency spillway discharge in the cell in column J and row corresponding to the highest value for the stage (column F) in the 10-year flood routing computation described in steps up to #11 above. If the emergency spillway crest elevation is set above the 10-year flood pool elevation, enter the formula in the cell in (column J) in the row below that having the highest value for stage in column F. Assuming that the emergency spillway would function as a broad-crested weir, enter the formula for the discharge as: $=2.65 * (\text{length of spillway}) * (F11 - \text{stage of the crest of emergency spillway})^{1.5}$. If the hydraulic characteristics of the spillway are different from that of a broad-crested weir, change the formula accordingly. Copy the formula from the cell in which the formula is entered and paste into all the cells below that in column J. The computations should be complete with this step. Obtain the design parameters from the values in the row in which the maximum stage and storage occurs.

FIGURE 1

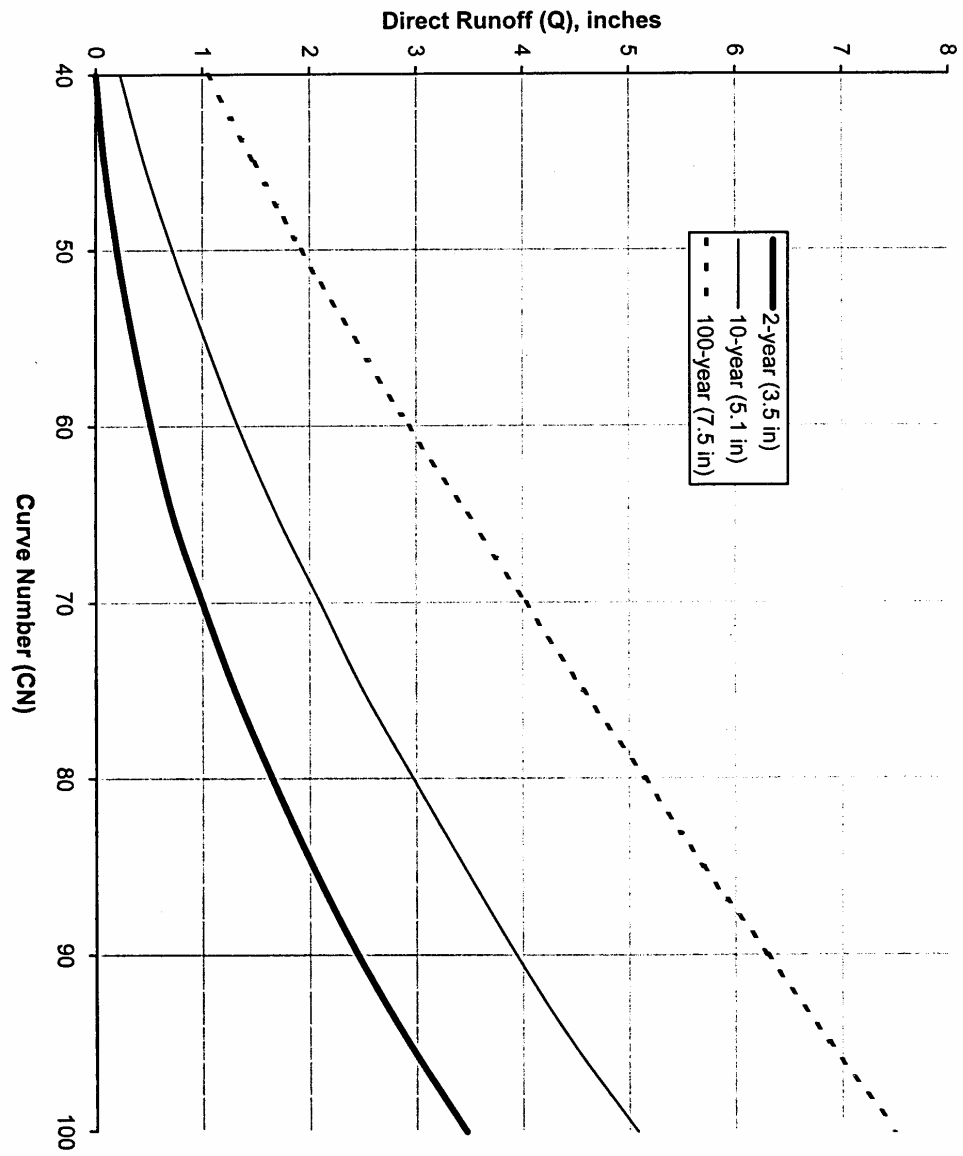


TABLE 1

Values for Runoff Curve Numbers

Curve Number	I _a (in)	Curve Number	I _a (in)
40	3.000	70	0.857
41	2.878	71	0.817
42	2.762	72	0.778
43	2.651	73	0.740
44	2.545	74	0.703
45	2.444	75	0.667
46	2.348	76	0.632
47	2.255	77	0.597
48	2.167	78	0.564
49	2.082	79	0.532
50	2.000	80	0.500
51	1.922	81	0.469
52	1.846	82	0.439
53	1.774	83	0.410
54	1.704	84	0.381
55	1.636	85	0.353
56	1.571	86	0.326
57	1.509	87	0.299
58	1.448	88	0.273
59	1.390	89	0.247
60	1.333	90	0.222
61	1.279	91	0.198
62	1.226	92	0.174
63	1.175	93	0.151
64	1.125	94	0.128
65	1.077	95	0.105
66	1.030	96	0.083
67	0.985	97	0.062
68	0.941	98	0.041
69	0.899		

TABULAR HYDROGRAPH UNIT DISCHARGES (CSM/IN)
(Greensboro--Type II Rainfall Distribution)

City of Greensboro
Stormwater Management Manual

	A	B	C	D	E	F	G	H	I	J
1				FLOOD ROUTING COMPUTATIONS (CHAIN SAW METHOD)						
2				(For 10-year, 24-hour Rain Event); Project: Typical Development						
3										
4	Site area = 20 acres; Post-develop. CN = 90; Tc = 20 Min.; 10-year Rain = 5.1 in.; Runoff = 4.0 in.									
5	Pond area at normal pool = 0.3 acre; Stage-Volume: $h=(V/13531)^{0.9}$; Target Peak Outflow = 42 cfs									
6										
7	Time	Tab. Hydr. Value	Inflow	Storage	Change in Storage	Stage	Outflow	Outflow Facilities (Spillways and Orifices)		
8	(Hours)	(csm/in)	(cfs)	(cu.ft.)	(cu.ft.)	(ft.)	(cfs)	Orifice	Prin. Spillway	Emerg. Spillway
9										
10	10.7	0	0	0	0	0	0	0	0	0
11	11	20	2.5	0	0	0	0	0	0	0
12	11.3	28	3.5	2700	2700	0.234439	0.598453	0.26132	0.337133705	0
13	11.6	41	5.125	5833.67	3133.670294	0.468976	1.238921	0.285066	0.953855593	0
14	11.9	118	14.75	10030.64	4196.965195	0.763833	2.295056	0.312368	1.982688547	0
15	12	235	29.375	14514.42	4483.779754	1.065179	3.603054	0.338	3.265054811	0
16	12.1	447	55.875	23792.32	9277.900411	1.661867	6.746569	0.383734	6.362834906	0
17	12.2	676	84.5	41478.55	17686.23514	2.740592	13.92971	0.454891	13.4748183	0
18	12.3	676	84.5	66883.86	25405.30461	4.213008	26.21996	0.537009	25.68294646	0
19	12.4	459	57.375	87864.67	20980.81606	5.385623	37.71455	0.594345	37.12020647	0
20	12.5	283	35.375	94942.43	7077.761302	5.77454	41.82502	0.612177	41.2128428	0
21	12.6	196	24.5	92620.43	-2322.007242	5.647278	40.46438	0.6064	39.85797537	0
22	12.7	146	18.25	86873.25	-5747.175161	5.3309	37.14768	0.591793	36.5558838	0
23	12.8	114	14.25	80070.09	-6803.16376	4.953662	33.31897	0.573891	32.74507541	0
24	13	80	10	66340.43	-13729.65581	4.182188	25.93706	0.535419	25.40164138	0
25	13.2	66	8.25	54865.75	-11474.68358	3.525123	20.15735	0.500325	19.65702749	0
26	13.4	57	7.125	46292.45	-8573.294042	3.025257	16.09976	0.471883	15.62787241	0
27	13.6	51	6.375	39830.63	-6461.823732	2.6424	13.20605	0.448881	12.7571679	0
28	13.8	46	5.75	34912.27	-4918.355138	2.34684	11.10808	0.430284	10.6777951	0
29	14	42	5.25	31054.46	-3857.816651	2.112101	9.531426	0.41492	9.116506028	0
30	14.3	37	4.625	26430.52	-4623.939881	1.82683	7.728819	0.395446	7.333372544	0
31	14.6	33	4.125	23078.39	-3352.124024	1.616918	6.486928	0.380481	6.106447444	0
32	15	31	3.875	19677.22	-3401.176249	1.400782	5.288362	0.36443	4.923932248	0
33	15.5	28	3.5	17133.17	-2544.051319	1.236679	4.436282	0.351754	4.084528109	0
34	16	24	3	15447.86	-1685.307935	1.126638	3.894667	0.342992	3.551675376	0
35	16.5	22	2.75	13837.46	-1610.401491	1.020361	3.395479	0.334312	3.061167302	0
36	17	20	2.5	12675.59	-1161.862484	0.942919	3.047212	0.327842	2.719370219	0
37	17.5	19	2.375	11690.61	-984.9821635	0.876711	2.760251	0.322208	2.438043112	0
38	18	18	2.25	10997.16	-693.4516499	0.829766	2.563015	0.318152	2.244863045	0
39	19	16	2	9870.305	-1126.855293	0.752836	2.251418	0.311392	1.940025219	0
40	20	13	1.625	8965.202	-905.1034323	0.69041	2.009591	0.305797	1.703794382	0
41	22	12	1.5	6196.143	-2769.058659	0.495122	1.322316	0.287591	1.034725215	0
42	26	0	0	8754.786	2558.642973	0.675809	1.954506	0.304474	1.650032761	0

Flood Routing: 10-year Rain Event

